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Growing Pains: Maturity Associated Variation in Injury Risk in Academy Football

Abstract

Reducing injuries to youth players is of primary importance to academies, as injuries can result in a significant loss in both training and match time, as well as negatively affecting player development. In total, 76 talented young football players were analysed over two full competitive seasons. The injury incidence and burden for **all non-contact and overuse** injuries were recorded. Exposure was calculated as the total number of competitive matches hours played. Somatic maturation was estimated by expressing the current height of each player as a percentage of their predicted adult height (Roche, Tyleshevski, & Rogers, 1983). The period of circa-peak height velocity (PHV) (**24.5 injuries per 1000 h**) was associated with a significantly higher injury incidence rate and burden compared to pre-PHV (**11.5 injuries per 1000 h; RR:2.15, 95%CI:1.37-3.38, $P<.001$**). No significant differences in injury risk between maturity timing groups were observed. The interaction effect between maturity status and maturity timing confirmed there is a risk period circa-PHV, but this was not dependent on maturity timing. The main practical application of this study is that football academies should regularly assess the maturity status of young footballers to identify those players with increased susceptibility to injury. Moreover, academies should individualise training and injury prevention strategies based on maturation.

Introduction

Football academies aim to identify and develop youth players capable of competing at the elite adult level and obtaining a professional contract (Le Gall, Carling, Williams, & Reilly, 2010). To achieve this objective, a considerable investment of both time and money is required (Ericsson, Krampe, & Tesch-Römer, 1993; Ford et al., 2011). Remaining injury free is a priority for young players as injuries can result in a significant loss in both training and match time, as well as negatively affecting player development, which includes technical, tactical, physical, and psychological factors (Johnson, Doherty, & Freemont, 2009; Price, Hawkins, Hulse, & Hodson, 2004). Research is warranted to combat the high frequency of injuries reported in elite male youth football players (Le Gall et al., 2006; Price et al., 2004; Read, Oliver, Croix, Myer, & Lloyd, 2016). These injuries at youth level can also make players more susceptible to future injuries and long-term health risks when adults (Swain et al., 2018; Webborn, 2012).

Investigations in youth football have shown that time loss per injury is highest in the U14 and U15 age groups (Read, Oliver, De Ste Croix, Myer, & Lloyd, 2017) and overall injury incidence rates are highest in the U14 age group (Le Gall et al., 2006). These ages generally coincide with the period of maximal growth known as peak height velocity (PHV), which occurs on average at 13.8 years (Malina, Bouchard, & Bar-Or, 2004). Although, due to individual variance in pubertal timing, not all boys will experience the growth spurt at this age. A review by Swain et al. (2018) suggested that currently, the effects of maturity timing on injury risk are unclear and require further investigation regarding how both maturity status and maturity timing influence injury risk.

Maturity status is defined as the state of maturation at the time of observation (Malina, Bouchard, & Bar-Or, 2004). In the current study, this was categorised based on whether the

player was pre-, circa- or post-PHV (Malina et al., 2004), where PHV is defined as the period of maximal rate of growth during puberty (Malina et al., 2004). Maturity status has previously been linked with injuries in youth football, with the period around PHV associated with significantly higher injury risk (Van der Sluis et al., 2014). Alternatively, Bult, Barendrecht, and Tak (2018) suggested that the period 6 months after PHV was associated with increased injury risk. Maturity timing is defined as the age at which a specific maturational event occurs; in the current study, this was defined using a Z-score offset to compare the individual to a reference sample (Bayer & Bayley, 1959). Two studies have analysed the effects of maturity timing on injury risk in youth football. Firstly, Van der Sluis, Elferink-Gemser, Brink, and Visscher (2015) suggested that later maturing players were at increased injury risk because they will experience the developmental changes of PHV at an older chronological age, where the demands of training and games have increased. In contrast, Le Gall, Carling, and Reilly (2007) found that earlier maturing players were at greater injury risk.

Several mechanisms have been hypothesized as to the cause of increased injury occurrence during adolescence. During PHV, there is a rapid growth of the whole body, as well as changes to limb length, limb mass and moments of inertia (Adirim & Cheng, 2003; Hawkins & Metheny, 2001). These changes can cause adolescents to experience delays or regressions in sensorimotor mechanisms due to increased growth (Quatman-Yates, Quatman, Meszaros, Paterno, & Hewett, 2012). Studies have also shown **changes** in interlimb asymmetry and neuromuscular control could both be affected by maturity timing and/or maturity status, again leading to an increased likelihood of injury (Read, Oliver, Myer, De Ste Croix, & Lloyd, 2018). During this period, there is also a temporary vulnerability of bodily tissues including muscle-tendon junctions, bone-tendon junctions, ligaments, growth cartilage and decreased bone density (Blimkie et al., 1993; Faulkner, Davison, Bailey, Mirwald, & Baxter-Jones, 2006; Van der Sluis et al., 2014). The intensive training programs that elite youth athletes participate in at

academy level, combined with the tissues' decreased load-capacity capabilities, could create an imbalance that leads to injury.

Studies are yet to analyse the interaction between maturity timing and maturity status upon injury risk. Athletes who mature early, on-time, or late could be at increased or decreased risk of injury during specific stages of the maturational process. Previous studies have also used the Mirwald, Baxter-Jones, Bailey, and Beunen (2002) maturity offset method to measure maturity status and maturity timing; the accuracy and reliability of this method to estimate actual age at PHV has been questioned pre- and post-PHV in longitudinal studies of growth in Polish youth (Kozieł & Malina, 2018). Maturity timing has also been shown to systematically influence the maturity offset prediction equation, with a decreased accuracy for both early and late maturing boys (Kozieł & Malina, 2018). **Skeletal age has also been used to assess maturity (Johnson, Doherty, & Freemont, 2009).** These methods, though objective and more reliable than somatic measures, are expensive and invasive in nature, making it difficult for clubs to implement in practice. The present study will build on these limitations and use the percentage of predicted adult stature, as an alternative index of maturation status and timing (Malina, Coelho E Silva, Figueiredo, Carling, & Beunen, 2012; Malina, Dompier, Powell, Barron, & Moore, 2007). The purpose of this study is to examine how variance in maturity status (pre-, circa- and post-PHV) and maturity timing (early, on-time and late) contribute to injury risk in a cohort of academy football players. This will be achieved through three research questions; (1) does injury risk change between players pre-, circa- and post-PHV, (2) does injury risk change dependant on maturity timing and (3) does the interaction between maturity status and maturity timing influence injury risk.

Method

Participants were 76 talented young football players from a Premier League Football club's academy. The age groups U11 to U16 were selected for analysis, as these age groups included a range of players from across the pre-, circa- and post-PHV stages. Data from two full competitive seasons (2016/2017 and 2017/2018) was analysed. The Research Ethics Approval Committee for Health at the host institution provided ethical approval for this study. As part of the enrolment in the academy, all parents provided consent and assent for routine data collection and the potential use of this data in research.

Exposure was calculated as the total number of competitive matches hours played (Hägglund, Waldén, Bahr, & Ekstrand, 2005). The exact training exposure for each player was not available due to the use of retrospective data. Match exposure information was gathered through the club's records for each measurement period. **There was a total of 3693 match exposures, with a mean exposure of 48 (\pm 23) per player. Participants without match exposure data were removed prior to analysis.**

The stature and mass of each player were measured by trained sports science staff on a regular basis. Maturity timing (pre-, circa- and post-PHV) and maturity status (early, on-time and late) were calculated at each measurement point. Players' height, weight, chronological age and mid-parent height were used to predict the adult height of each player (Khamis & Roche, 1994). The heights of the biological parents of each player were self-reported and adjusted for over-estimation using the equations in Epstein, Valoski, Kalarchian, and McCurley (1995). The current height of each player is then expressed as a percentage of their predicted adult height (POAH), which can then be used as an index of somatic maturation (Roche et al., 1983). Applying this method, the median error bounds between actual and predicted mature height from 4 to 17 years of age in males ranges from 0.8 to 2.8 cm (Khamis & Roche, 1994).

Maturity status was calculated using each player's POAH; this variable separated players into three groups (Pre-, Circa- and Post-PHV). Circa-PHV was defined as between 88% and 95% of predicted adult stature. Subsequently, pre-PHV was $<88\%$ and post-PHV was $>95\%$ (Cumming, Lloyd, Oliver, Eisenmann, & Malina, 2017). The degree to which players were early, on-time or late in maturation was expressed as Z-score relative to participants percentage of adult stature attained at measurement age from the Berkeley longitudinal study reference data (Bayer & Bayley, 1959). Players were classified as on-time if their Z-score fell between $+0.5$ and -0.5 , advanced if their Z-score $>+0.5$ or delayed if their Z-score <-0.5 . Due to a low prevalence of late maturing players, the groups of on-time and late classification were combined for analyses involving the interaction between maturity timing and stage. Subsequently, early was classified as Z-score $>+0.5$ and on-time/late was a Z-score $<+0.5$.

Time-loss injuries were assessed and recorded by the Academy medical staff using the club's online database. Time-loss injuries were defined as those preventing a player from participating in full training or matches (Van der Sluis et al., 2015). This study only considered non-contact injuries defined as those sustained by a player without extrinsic contact by another player or other object on the field of play (Marshall, 2010). The duration between the day of injury and the return to full training or match play was also recorded as the number of days missed. The incidence rate and the mean days missed per injury were multiplied to calculate the injury burden.

All statistical analysis was conducted using IBM SPSS Statistics for Windows (Version 23.0, Armonk, NY, USA). Generalized linear mixed-effects models (GLMM) were used to model the association between maturity status, maturity timing, and their interaction, upon both injury incidence and injury burden, using a Poisson distribution and log-link function. The predictor variables were modelled as categorical fixed effects. Player ID was included as a

random effect to account for repeated observations. All models were offset for each individual players' match exposure (Williams, Trewartha, Cross, Kemp, & Stokes, 2017). Statistical significance was accepted at $P < 0.05$.

Results

Descriptive injury data for each age group are shown in Table 1. Overall match injury incidence was 15.8 per 1000 h, and the injury burden was 342 days per 1000 h. The injury incidence rate was highest in the U14 age group, whilst the injury burden was highest in the U15 age group.

Table 1 – Descriptive injury statistics summarised for each age group.

Age Group	U11	U12	U13	U14	U15	U16
Number of Players	24	21	22	15	16	14
Sum of match exposure (h)	825	897	933	1036	1247	648
Total number of injuries	6	12	16	23	20	11
Total days lost	67	221	191	484	647	191
Injuries per 1000 match h	7.3	13.4	17.1	22.2	16.0	17.0
Injury burden per 1000 match h	81	246	205	467	519	295
Mean injury duration	11	18	12	21	32	17

Regarding maturity status, the injury incidence was significantly higher circa-PHV (24.5 injuries per 1000 h) versus pre-PHV (11.5 injuries per 1000 h; RR:2.15, 95%CI:1.37-3.38, $P<.001$) (Figure 1). Similarly, injury burden was significantly higher circa-PHV (560 days per 1000 h) versus pre-PHV (182 days per 1000 h; RR:3.25, 95%CI:1.74-6.06, $P<.001$). The likelihood of injury was not significantly higher post-PHV (16.4 injuries per 1000 h) compared to pre-PHV (11.5 injuries per 1000 h) (RR:1.45, 95%CI:0.74-2.82, $P=0.28$). Injury burden was, however, significantly higher post-PHV (435 days per 1000 h) compared to pre-PHV (RR:2.02, 95%CI:1.03-3.99, $P=<0.05$). There were no significant differences in injury risk between post and circa-PHV ($P>0.05$).

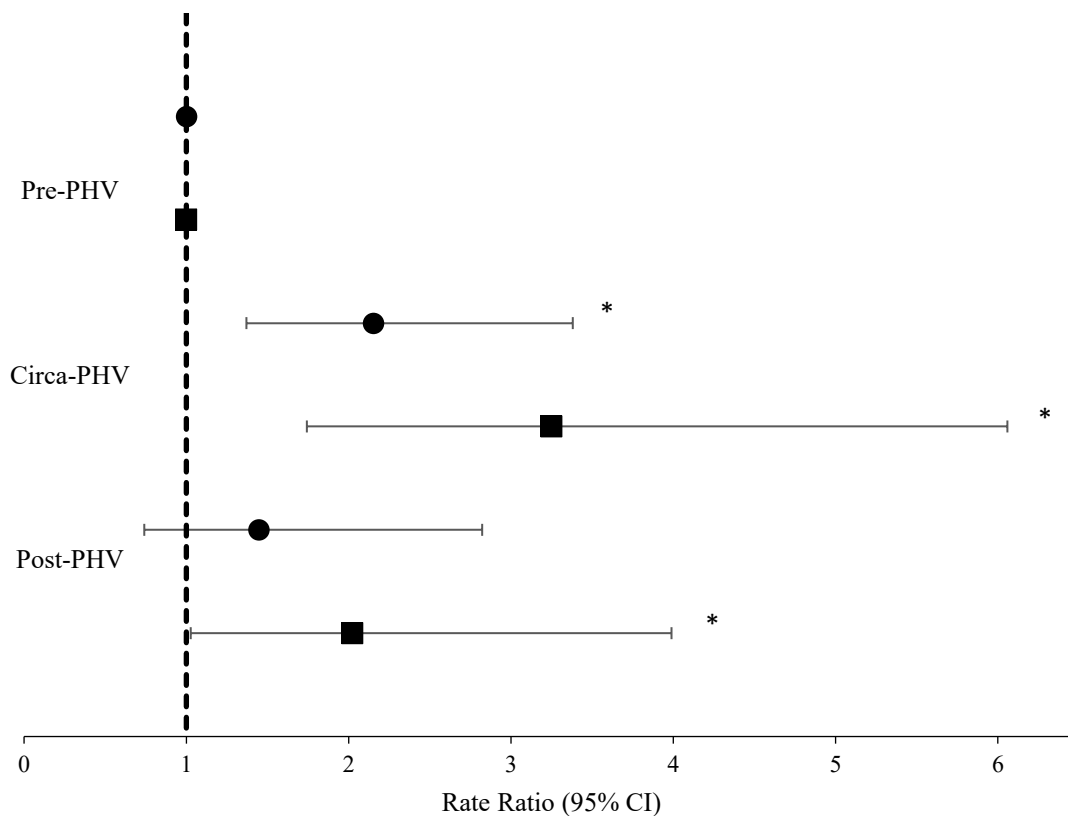


Figure 1. Data points represent RR of injury measures across each maturity status group relative to ‘pre-PHV’ (reference group), after accounting for maturity timing (●=Injury Incidence, ■=Injury Burden and * denotes a significant difference, $P < 0.05$).

The rate ratios showed no significant difference between any maturity timing groups after accounting for maturity status (Figure 2). For late maturing players the injury incidence rate (6.4 injuries per 1000 h) was lower than on-time players (18.5 injuries per 1000 h; RR: 0.51, 95% CI: 0.23-1.16), however, this difference was not statistically significant ($P=0.11$).

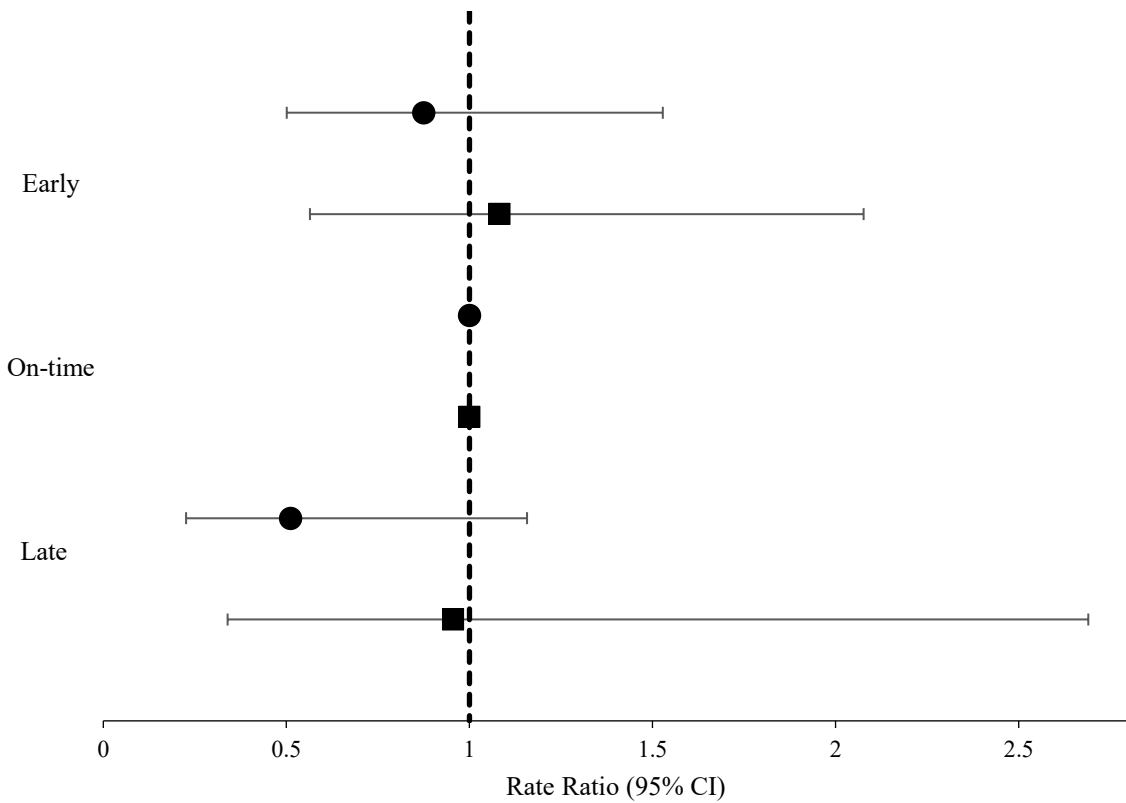


Figure 2. Data points represent RR of injury measures across each maturity timing group relative to ‘on-time’ (reference group), after accounting for maturity status (●=Injury Incidence, ■=Injury Burden and * denotes a significant difference, $P<0.05$).

For the interaction between maturity status and maturity timing, there was a significantly greater likelihood of injury incidence for players that were early maturers and circa-PHV (RR: 2.42, 95% CI:1.22-4.81, $P=0.01$) and for on-time/late maturers and circa-PHV (RR: 2.50, 95% CI:1.53-4.07, $P=0.0003$) when compared to on-time/late players that were pre-PHV (Figure 3a). All other comparisons did not demonstrate significant differences. Injury burden was significantly higher for players that were on-time/late maturers and circa-PHV (RR: 3.51, 95% CI:1.74-7.07, $P=0.0004$) and for players which were early maturers and post-PHV (RR: 2.45, 95% CI:1.07-5.61, $P=0.034$) when compared to on-time/late maturers that were pre-PHV (Figure 3b). All other variables did not demonstrate significant differences.

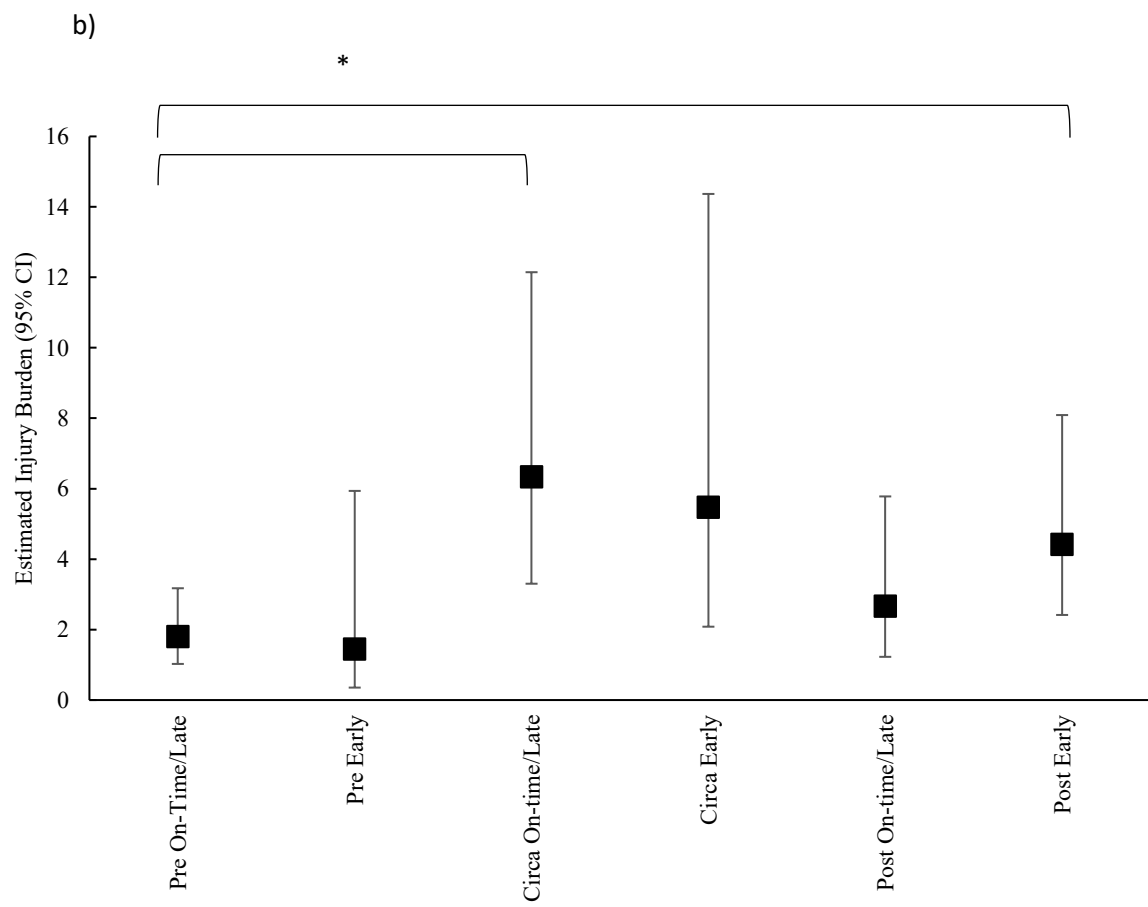
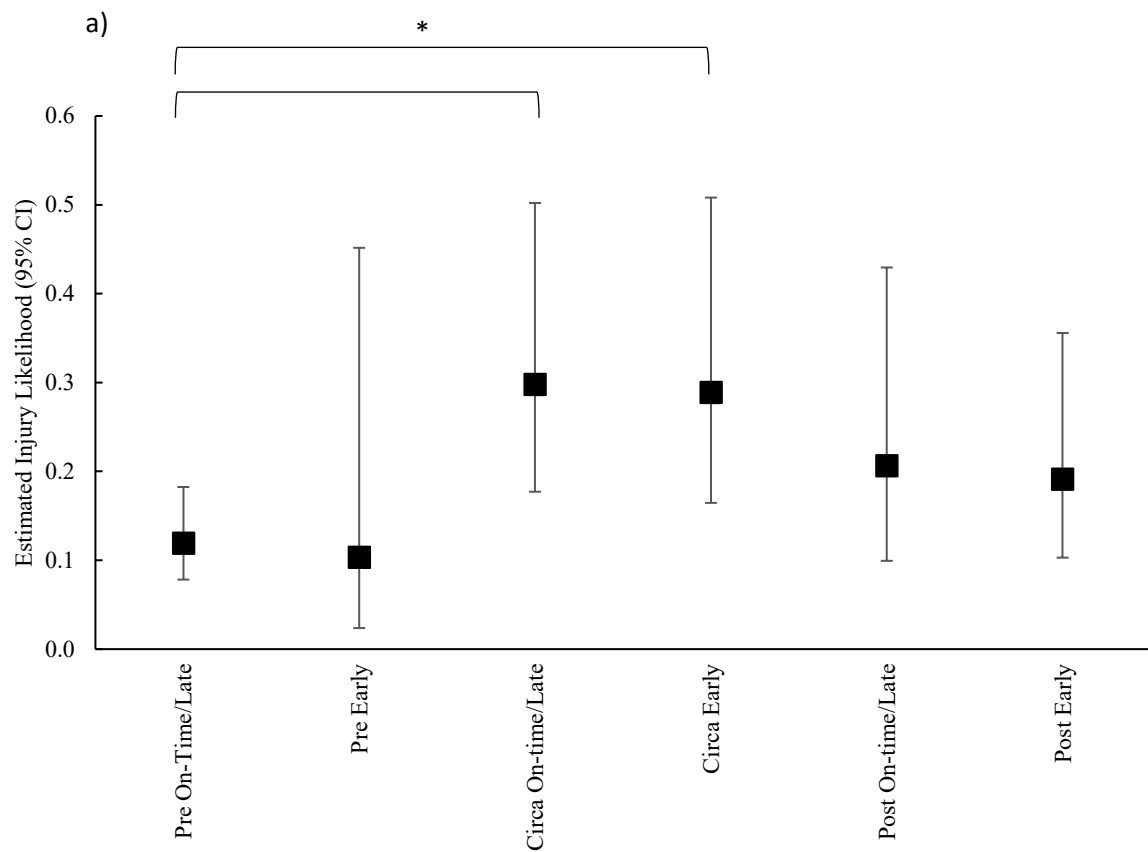


Figure 3a. shows the injury incidence estimated marginal means for the interaction between maturity status (pre-, circa- and post-PHV) and maturity timing (early and on-time/late) with 95% confidence intervals. 3b. shows the injury burden estimated marginal means for the interaction between maturity status (pre-, circa- and post-PHV) and maturity timing (early and on-time/late) with 95% confidence intervals.

Discussion

This study aimed to investigate how **maturity status (pre-, circa-, post-PHV)** and **maturity timing (early, on-time, late)** influences injury risk in academy football. The U13 and U14 age groups had the greatest number of injuries per 1000 hours, supporting the concept of increased vulnerability during adolescence. Maturity status was the factor most associated with injury incidence and burden, **more specifically players circa-PHV had a significantly greater injury incidence and burden**. Further, no differences in injury incidence or burden were associated with maturity timing groups after accounting for maturity status. The interaction effects further confirmed an increased injury risk circa-PHV, and this did not differ depending on maturity timing.

Similar to the findings of this study, previous literature also found overall injury rates were highest in the U14 age group (Le Gall et al., 2006). Our results also demonstrated that the injury burden was greatest in the U14 and U15 ages groups, which agrees with other previous work (Read et al., 2017). The difference between the injury incidence and injury burden findings is due to the increased mean injury severity in the U15s age group. Players during these ages continue to grow rapidly and could experience more severe injuries due to the concomitant increase in training load demands during this period (Barnes, Archer, Hogg, Bush, & Bradley, 2014; Goto, Morris, & Nevill, 2015).

The first research question was to understand how injury risk changes between players pre-, circa- and post-PHV. There was a significantly higher risk of injury for the circa-PHV group compared to the pre-PHV group. More specifically, players circa-PHV had a 115% increase in injury incidence and a 225% greater injury burden. There are various possible reasons for an increased injury occurrence and burden circa-PHV. Firstly, during PHV the vulnerability of bodily tissues increases, including changes to muscle-tendon junctions, bone-

tendon junctions, ligaments, growth cartilage and bone density (Blimkie et al., 1993; Faulkner et al., 2006; Van der Sluis et al., 2014). As previously noted this may arise from the many changes in size, shape and function that accompany the pubertal growth spurt (Adirim & Cheng, 2003; Hawkins & Metheny, 2001; Quatman-Yates et al., 2012; Read, Oliver, Myer, De Ste Croix, & Lloyd, 2018).

These findings are in agreement with both Van der Sluis et al. (2014) and Bult et al. (2018), who demonstrated that this phase of development was associated with increased injury incidence and injury burden. It should be noted that, to the authors' knowledge, the current study is the first to use POAH to identify periods of risk. This measurement method differs from both the Van der Sluis et al. (2014) and Bult et al. (2018), which used the maturity offset method. As previously noted, the reliability and validity of the maturity offset method has been questioned (Kozieł & Malina, 2018). Thus, the results from all three studies cannot be directly compared with one another. Van der Sluis et al. (2014) identified 6 months before and after PHV as the period of increased injury incidence and injury burden. Alternatively, Bult et al. (2018) identified the 6 months after PHV as the period of increased risk. The results of the current investigation show a mixed outcome for the post-PHV group; the injury incidence rate in this stage was not significantly greater than pre-PHV, but the injury burden rate was significantly greater. This suggests that the effects of injuries appear to be more severe post-PHV. Another possible reason for this is that staff might be more cautious with return-to-play at older age-groups as professional contracts are offered at this stage. Further research is, however, warranted to confirm this speculation.

With respect to the impact of maturity timing upon injury, the current investigation found that the injury incidence was highest in the early and on-time players. That said, the rate ratios revealed no significant difference between early, on-time and late maturing players for both injury incidence and burden once maturity status had been controlled for. This observation

agrees with Le Gall's et al. (2007), which found a higher injury incidence in more mature players compared with the late-maturing group, however, neither study achieved statistical significance. Early maturing players are possibly more likely to be injured due to the selection bias observed in academy football, which favours this group (Figueiredo, Gonçalves, Coelho e Silva, & Malina, 2009; Johnson, Farooq, & Whiteley, 2017). That is, players advanced in maturation and more likely to be selected to compete in competition and play central roles (Towlson, Copley, Parkin, & Lovell, 2018). Contrary to the findings of this study, Van der Sluis et al. (2015) suggested later maturers had a greater risk of injury. Moreover, they reported a seven-fold higher incidence of overuse injuries in late maturing players compared to their earlier maturing counterparts. The type of injury was not analysed within the present study, but future research should consider how different types of injury could be affected by maturity status. It should also be noted that Van der Sluis et al. (2015) used the Mirwald method (Mirwald et al., 2002), which differs from the current study. The present study also differs in the groups used; players in this study were split into three groups based upon Z-scores (early, on-time and late), whereas, Van der Sluis et al. (2015) split the players into two groups of "earlier" and "later" maturers.

The final aim of this study is to investigate the interaction between maturity status and maturity timing effect injury risk. For this analysis, the late maturing group was combined with the on-time group, due to there being no injuries recorded for late maturing players circa-PHV and no late maturing players recorded post-PHV. These groups could be combined as previous analysis demonstrated that after maturity status was controlled, there was no effect of maturity timing on both injury incidence and injury burden. This finding suggests the risk period associated with players which are circa-PHV is not dependent on whether players are early or on-time/late maturer. This information supports the previous findings; firstly, players within this sample were at greater risk of injury between 88% and 95% of predicted adult stature.

Moreover, the interaction also shows the effects of maturity timing were smaller or unclear in comparison to the effect of increased vulnerability during adolescence.

The results of this current study have important implications for practice. Academies should regularly assess the maturity status of young footballers to identify those players most likely to be experiencing an increased risk of potential injury. **Players circa-PHV** have a 115% increase in injury incidence and a 225% greater injury burden. Moreover, injury reduction strategies should be implemented for at-risk players, as well as, making coaches and players aware of this increased susceptibility. Such strategies could include motor skill development, balance activities, core strength activities and reduced loading (Wormhoudt, Teunissen, & Savelsbergh, 2013).

The limitations of the current investigation should also be noted. The findings of the current study apply to this specific group of players from a single football academy, and may not be generalizable to other populations. Furthermore, when interpreting these findings caution must be taken as injuries are complex and other factors contribute to risk beyond those analysed in this study. Additionally, the present study has only used match time to account for overall exposure. Another limitation of this study is the underrepresentation of late maturing players; unfortunately, this group is a minority across academy football and has been found in previous samples (Johnson et al., 2017).

Future research should attempt to overcome some of the limitations of this work by attempting to quantify and understand how training load and interventions could affect the relationship between maturity status, maturity timing and injury risk. The impact training volume and load is currently unknown in the adolescent football players (Read et al., 2016). To date, there is only one published study which has analysed the relationship between training load, maturation and injury, Horobeanu, Jones, and Johnson (2017) suggested the days missed

due to Osgood Schlatter's disease could be significantly reduced through monitoring maturation, symptoms and subsequently reducing training load. Future studies should also further analyse how maturity status and maturity timing may affect different types of injury (e.g. growth-related and overuse injuries) and whether particular injuries are more likely at the acceleration, peak or deceleration phases of the growth spurt.

In conclusion, the present study observed a significant increase in injury incidence and injury burden circa-PHV. Through the regular measurement and monitoring of growth and maturity in young athletes, it should be possible to better identify high-risk phases of the growth spurt to enable the appropriate adjustment of training load and content. Future studies could build on this by understanding how training load could influence the relationship between maturity status and injury and by implementing strategies to reduce injury risk during this period.

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